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ABSTRACT

This study was designed to examine preservice elementary teachers' beliefs about the nature of science, document changes in these beliefs over the duration of a year-long science methods course and embedded teaching practicum, and assess the impact of these beliefs on their classroom practice (Bright, 2001). The pre-test and post-test case study design measured (n=50) elementary preservice teachers' beliefs about the nature of science prior to and after participation in an 18-week elementary science methods course and 6 week intervening teaching practicum. Classroom observations documented the general structure of two science lessons, the types of questions asked, the students' responses, and handouts and assignments provided for each of six preservice teachers. Unit overviews, lesson plans, and portfolio assignments were collected and analyzed to provide triangulation of the classroom observations. Significant gains were made between the pre-test and the post-test scores for the preservice teachers' beliefs on the creative, developmental, and unified subscales, and the total Nature of Scientific Knowledge Survey. Results from the classroom observations indicated that the preservice teachers' beliefs about the nature of science were not clearly related to their classroom practice. Although the course assignments indicated a commitment and understanding of science as inquiry processes, and the modified learning cycle, these preservice teachers were unable to fully implement the engage-explore-consolidate-assess approach and productive questioning strategies during their initial practicum. (Contains 75 references.) (Author/JDM)

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# Elementary Preservice Teachers' Beliefs about the Nature of Science and Their Influence on Classroom Practice

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Abstract

This study was designed to examine preservice elementary teachers' beliefs about the nature of science, document changes in these beliefs over the duration of a year-long science methods course and embedded teaching practicum, and assess the impact of these beliefs on their classroom practice (Bright, 2001). The pretest and posttest case study design measured 50 elementary preservice teachers' beliefs about the nature of science prior to and after participation in an 18-week elementary science methods course and 6-week intervening teaching practicum. Classroom observations documented the general structure of two science lessons, the types of questions asked, the students' responses, and handouts and assignments provided for each of six preservice teachers. Unit overviews, lesson plans, and portfolio assignments were collected and analyzed to provide triangulation of the classroom observations.

Significant gains were made between the pretest and the posttest scores for the preservice teachers' beliefs on the creative, developmental, and unified subscales, and the total *Nature of Scientific Knowledge Survey*. Results from the classroom observations indicated that the preservice teachers' beliefs about the nature of science were not clearly related to their classroom practice. Although the course assignments indicated a commitment and understanding of science as inquiry, science processes, and the modified learning cycle, these preservice teachers were unable to fully implement the engage-explore-consolidate-assess approach and productive questioning strategies during their initial practicum.

# Elementary Preservice Teachers' Beliefs about the Nature of Science and Their Influence on Classroom Practice

## Introduction

Science education reforms initiated in the 1980s and that continue today focus on science for all children and a balance of science knowledge, process, and habits of mind (Science Council of Canada, 1984). Although current science curricula may vary in the science topics, there is consensus on the importance of developing science literacy for all students, an understanding of the nature of science, and using constructivist teaching approaches (Hogan, 2000; Lederman, 1992; McComas *et al.*, 1998). Documents like *Benchmarks for Science Literacy* (AAAS, 1993) and the *National Science Education Standards* (NRC, 1996) in the United States and the *Common Framework of Science Learning Outcomes* (CMEC, 1997) in Canada incorporate these ideas into the goals of science literacy and into teaching science as inquiry. The goal of science literacy cannot be achieved without first understanding the nature of science: the epistemology and ontology of scientific knowledge (Hogan, 2000; McComas *et al.*, 1998).

Teachers struggle to implement the current science reforms at the classroom level. Often science instruction encourages students to memorize isolated ideas rather than establish meaningful connections between concepts. In addition, science is taught too infrequently to be effective (Duschl, 1983; McDevitt *et al.*, 1993; Tobin *et al.*, 1990). Inservice instruction, such as workshops for teachers, is one way to address the current challenges of science teaching in elementary classrooms. Unfortunately, professional development for practicing teachers has not been overwhelmingly successful in the last 40 years (Supovitz & Turner, 2000). Short-term approaches do not acknowledge that teachers' attitudes toward and methods of teaching science have been formed over a long period of time, and that changes in teaching behaviours, like conceptual changes, do not occur with short interventions. Gabel and Rubba (1979) measured the attitudes of practicing teachers immediately after a science inservice workshop and again one year later. They found that the majority of participating teachers reverted to their original attitudes after one year. This would suggest that improving the current state of elementary science

instruction must begin in preservice science methods courses. This paper reports on a study of preservice teachers, their beliefs and their classroom practice (Bright, 2001).

## Background

A contemporary view describes science as a human endeavour that attempts to make sense of the natural world. Science is a process of successes and failures that is tentative and always changing based on further study and additional questions, and has elements of curiosity and creativity (Cross, 1990; Haack, 2002; McComas *et al.*, 1998; Vasquez, 1997). While this is the accepted view of the nature of science, elementary preservice teachers often have the preconception that science is a set of conclusions and knowledge to be acquired (Duschl, 1983; Zeitler, 1984). Science textbooks and science teaching frequently "emphasize the factual recall of science content to the near total exclusion of the knowledge-generation process" (McComas *et al.*, 1998, p. 4).

Preservice teachers' beliefs about science, the structure of science knowledge, and the scientific enterprise lead them to envision science teaching as disseminating or transmitting knowledge. Some research studies suggest that the lack of content knowledge is the cause of elementary teachers' reluctance to teach science through inquiry (Sumrall, 1997). Increasing the number of content courses taken by preservice teachers, however, does not automatically increase the use of inquiry-based teaching strategies in the classroom (Chubin, 1990; Loucks-Horsley & Matsumoto, 1999). Tilgner (1990) suggested that many content courses are taught with the view that a body of knowledge must be acquired and there is little emphasis on the processes of science. When the preservice teacher is presented with the view that science is more than a body of knowledge that includes skills, processes, attitudes, and habits of mind, a dilemma exists about how science should be taught in the elementary school (Duschl, 1983; Yore, 2001). While the need for a strong science content knowledge is important, the preservice teacher must also be shown the importance of science processes and the associated pedagogy (Zeitler, 1984).

Elementary science methods courses should provide preservice teachers with the following pedagogical content knowledge and opportunities: direct experience with hands-on,

process-oriented activities that can be used in their classroom and do not rely on a textbook as the sole information source, an understanding of the nature of learning and knowledge in science, and an opportunity to practice what they have learned in their science methods course (Glass *et-al.*, 1993; Ryks-Szelekovsky, 1993). Including the nature of science in preservice teacher education may be done in a variety of ways. McComas (1998) proposed four approaches to teaching the nature of science: in science methods courses, as part of science content courses, through authentic experiences with scientists, or as a formal course required in teacher education programs. However, "because a teacher has an understanding of the nature of science does not mean they know how to integrate forcefully such topics within instruction" (McComas *et al.*, 1998, p. 20), knowing by way of rote memorization does not always lead to meaningful learning– making the connection between new knowledge and what is already known and applying the resulting knowledge network to relevant problems.

Researchers vary in their conclusions on the relationship between teachers' beliefs about the nature of science and their instructional planning and practice. Duschl (1987) suggested that teachers must have an understanding of the nature of science in order to incorporate inquiry-based or constructivist-based teaching methods. Lederman and Zeidler (1987) disagreed, suggesting that preservice teachers' beliefs about the nature of science do not influence teaching behaviour. Crawford (1999) suggested that the barriers to implementing inquiry-based learning in the classroom may not be influenced by preservice teachers' beliefs about the nature of science but rather by the inexperience of the preservice teacher in several knowledge domains "of teaching, including pedagogy, pedagogical content knowledge, knowledge of students, and knowledge of classrooms" (p. 175).

## Nature of Science

A definition of science that is useful to science teachers describes "the function, processes and limits of science rather than to engage students in the somewhat arcane arguments that occur among philosophers of science" (McComas *et al.*, 1998, p. 6). Hand *et al.* (2001) described traditional, contemporary, and postmodern views of science. These views address ontological and

epistemological issues of how scientific knowledge develops, the assumptions inherent in the development, and the purpose of science knowledge.

The traditional (realist, absolutist) view of science suggests that science knowledge consists of true descriptions and explanations of the real world, epistemologically developed through inductive reasoning and validated through deductive reasoning. Facts are accumulated by making observations, and these observations are interpreted and generalized to form a conception about reality. The traditional view of science proposes that the truth about reality (theory, law, principle, concept, or fact) is proven by the evidence gained through a series of observations and trials. Ideas developed through inductive reasoning cannot be tested based on the same evidence used to create the generalization since this would result in circular logic. McComas (1998) cautioned that sufficient evidence may be impossible to collect since the observations must hold true for all situations, past, present, and future. The validity of a generalization is tested through the process of deduction. Deductive reasoning occurs when a general rule exists and is used to explain other events and predict unwitnessed and future observations. Thomas Kuhn suggested that deductive reasoning is like a puzzle, rather than a problem, since the solution is already known from the outset (Janzen & Voogt, 1998). Scientific knowledge, according to the traditional view, is a collection of absolute truths that is unchanging; and the scientific method is a linear, step-by-step process (Palmquist & Finley, 1997). The scientific method itself provides validation to the knowledge claim as this process is controlled and the scientist is objective. McComas (1998) suggested that objectivity for the scientist is a myth because the scientist most often comes to the process with prior conceptions and passions that affect what he or she looks for and sees.

The contemporary (naïve realist, evaluativist) view of science proposes that science knowledge is a set of temporary descriptions and explanations that best fit the existing evidence and current understanding of the real world within the limitations of peoples' sensory and intellectual abilities. Science knowledge epistemologically develops with a hypothesis (causation statement) and data that are collected and support or refute the hypothesis. Hypothetico-deductive reasoning relies on the absence of refuting evidence and the presence of confirming

evidence as support for a hypothesis. Knowledge claims are not absolute, only supported or falsified. A hypothesis cannot be proven, but increasing support leads to a greater level of certainty, and one non-confirming observation may provide cause for the hypothesis to be rejected (Yore, 1992). Observed patterns of data that would either confirm or refute the hypothesis are predicted prior to data collection, and these predictions are then compared with the collected data to support or reject the original hypothesis (Yore, 1993). From an ontological perspective, these temporary descriptions and explanations are expected to change over time and more closely reveal accurate insights about reality. The development of science knowledge may not begin with a totally untested hypothesis but may begin with questioning an established description, explanation, or existing theory (canonical science). Furthermore, the evaluativist view recognizes the importance of the scientists' past experiences, prior knowledge, and beliefs and values. Although these beliefs and experiences may influence data interpretation, all interpretations require public scrutiny. McComas (1998) suggested that, since scientists have preconceptions about the outcome of an investigation, most evidence the scientist collects would confirm or support the existing hypothesis rather than refute the hypothesis. Palmquist and Finley (1997) suggested that the scientific method, within the contemporary view of science, is not bound by a single, universal set of steps but the method employed by a scientist depends on the circumstances.

The postmodern (idealist, relativist) view of science proposes that science knowledge consists of multiple descriptions and explanations of reality and it is impossible to know which of the interpretations, if any, are accurate since observation and interpretation cannot be separated. From an epistemological perspective, people use multiple ways to construct these explanations in the context of their personal beliefs. The ontological basis stresses that the limitations of people will not allow accurate descriptions of the world resulting in multiple realities, and that different explanations of the natural world are considered of equal value and are not questioned or judged by others since people can never know the truth about the natural world (Good *et al.*, 1999). Feminist science and multicultural science educators suggest that the epistemology of science is influenced by culture, language, and gender (Brickhouse, 2001; Snively

& Corsiglia, 2001). Postmodernists hold that the realist, absolutist view of science is so influenced by gender that it becomes a barrier to participation for women and people of colour, alternative life styles, and some cultures because the language and ideas are created by mostly white males. Brickhouse (2001, p. 284) stated that "the construction of alternatives to the conventional dualisms of objectivity/subjectivity, mind/body, masculine/feminine are part of what is necessary to create a science that is truly by and for everyone".

A review of international reform documents suggests that there is some agreement regarding the nature of science (Lederman, 1992; McComas *et al.*, 1998). McComas *et al.* (1998) stated that the following objectives characterized the nature of science common to many of the science curriculum standards documents:

> Scientific knowledge, while durable, has a tentative character. Scientific knowledge relies heavily, but not entirely, on observation, experimental evidence, rational arguments, and skepticism. There is not one way to do science (therefore, there is no universal step-by-step scientific method). Science is an attempt to explain natural phenomena. Laws and theories serve different roles in science; therefore, students should note that theories do not become laws even with additional evidence. People from all cultures contribute to science. New knowledge must be reported clearly and openly. Scientists require accurate record keeping, peer review, and replicability. Observations are theory-laden. Scientists are creative. The history of science reveals both an evolutionary and revolutionary character. Science is part of social and cultural traditions. Science and technology impact each other. Scientific ideas are affected by their social and historical milieu. (p. 6)

This consensus view of science suggests a contemporary middle-of-the-road view rather than a traditional or a postmodern view of science. These science reform documents focus on science as inquiry, evaluation, and debate rather than the traditional view of a set of unchanging truths that result from step-by-step procedures interpreted by unbiased scientists, or the postmodern view that proposes all knowledge claims are equally valid. Science is a tentative explanation that attempts to describe and explain general patterns of events in the natural world. These

descriptions and explanations are scrutinized by the science community and can be revised or supported within the scientific community.

Documents like *Benchmarks for Science Literacy* (AAAS, 1993) and the *National Science Education Standards* (NRC, 1996) in the United States present a contemporary view of science that judges claims based on presented evidence and accepts that all knowledge claims are tentative and may be changed with successive rounds of testing and observations. "Explanations on how the natural world changed based on myths, personal beliefs, religious values, mystical inspiration, or authority may be personally useful and socially relevant, but they are not scientific" (NRC, 1996, p. 201). The Canadian reform document *Common Framework of Science Learning Outcomes* (CMEC, 1997) is slightly different than its American counterpart in that it suggested that the components of science education include science, technology, society, and environment (STSE). The inclusion of technology and society suggests that this reform document can be interpreted as an evaluativist view of science with a postmodern perspective.

Alters (1997) suggested that the nature of science is a major goal in science education and yet there is no single agreed upon view of science that has a sound philosophical basis. Science educators, however, have come to some agreement on the nature of science to establish workable foundations for decisions about what to teach and how to teach science (Lederman, 2001). Much of this agreement centers on a contemporary evaluativist view of science. Although this contemporary view of science is not one used by some philosophers of science, it is a view that can guide teachers' decisions about instructional content and practice and is consistent with the constructivist learning and teaching theory endorsed by current science reform documents. Staver (1998, p. 517) stated that "the empirical character of science, as expressed in the thoughts and actions of scientists who seek to know, to bring coherence to our individual experiential worlds and collective knowledge through observation, experimentation, and the adjudication of results and theories needs no change within a constructivist framework".

Interactive-Constructivist Interpretation of Constructivism

Many 'faces' of the constructivist learning theory have been described in the research literature (Airasian & Walsh, 1997; Good, *et al.*, 1993; Phillips, 1995; Shymansky *et al.*, 1998; Yore, 2001). These individual perspectives on constructivism share some common points but have some critical differences related to the ontological worldview, view of reality, epistemic view of science, locus of mental activity, pedagogical structure, and the type and purpose of discourse (Yore, 2001). The various interpretations of constructivism share the premise that knowledge is constructed by the learner within the context of her or his personal experiences, that the learners' prior knowledge plays a role in the construction of knowledge, and that this prior knowledge may contain misconceptions unrelated to age, intelligence, and culture (Airasian & Walsh, 1997). Information processing, interactive-constructivist, social constructivist, and radical constructivist are interpretations of constructivism and involve different assumptions about the nature of science, learning, and pedagogy and lead to differences in design and delivery of science instruction (Yore, 2001; Table 1). The science methods course central to this case study promoted an interactive-constructivist approach to elementary school science instruction.

Table 1: Four Faces of Constructivism (adapted from Henriques, 1997).

| Feature | Information Processing | Interactive-Constructivist | Social Constructivist | Radical Constructivist |
|---|---|---|---|---|
| Worldview | Mechanistic | Hybrid | Contextualistic | Organistic |
| Ontological View | Realist | Naive Realist | Idealist | Idealist |
| Epistemic View | Absolutist (traditional) | Evaluativist (modern) | Evaluativist (postmodern) | Relativist (postmodern) |
| Judgment Criteria | Nature | Nature | Social Agreement | Self |
| Psychological: Locus of Mental Activity | Private | Public and Private | Public | Private |
| Pedagogical: Instructional Agenda | Teacher | Shared: Teacher and Individuals | Group | Individual |
| Linguistic: Role of Discourse | One-Way: Teacher to Student | Two-Way: Negotiations to SurfaceAlternatives and to Clarify | Two-Way: Discussion Leading to Consensus | One-Way: Individual to Self (inner speech) |

Interactive-constructivists "utilize a ecology metaphor to illustrate learning in which dynamic interactions of prior knowledge, concurrent sensory experiences, belief systems, and other people in a sociocultural context lead to multiple interpretations that are verified against evidence" (Shymansky *et al.*, 1998, p. 4). The view of science and scientific knowledge for the interactive-constructivist approach is a naïve realist, evaluativist view of science knowledge. Learning occurs in both a public and private domain often resulting in a variety of understandings across a group of learners. The students construct knowledge in the public domain through their interactions with other people and their surroundings. Meaning is further developed and internalized when students reflect on these interactions in the private domain. The teacher does not assume the role of expert but shares the control of the instructional agenda with the students. Students' initial ideas about a topic are the starting point for instruction. The teaching strategies maintain a focus on the students' ideas (Yager, 1991). The communications involve two-way negotiations between teacher and students to examine alternatives and to clarify thinking, rather than one-way communication from the teacher to the students telling them what they need to know.

Henriques (1997, p. 22) proposed that the interactive-constructivist approach has the following attributes:

- alignment among outcomes, instruction, resources and assessment;
- outcomes of conceptual change, conceptual growth, and metacognitive strategic learning;
- does not 'rule out' direct instruction embedded in a natural context of need;
- supports big ideas/unifying concepts (AAAS, 1993; NRC, 1996), science literacy and habits of mind needed to attain scientific literacy;
- requires students to gain ability to construct [conceptual understanding], to think critically, and to communicate their constructions and persuade others of their value or utility;

- encompasses guided inquiry, learning cycles, conceptual change and generative approaches; and
- teaching involves accessing, engaging, experiencing/exploring, justifying/rationalizing, consolidating/integrating old and new, and applying knowledge.

The various interpretations of the constructivist theory can be viewed on a continuum that emphasizes different aspects of ontology and epistemology (Henriques, 1997). Each interpretation has pedagogical or sociopolitical support, but it is hard to envision a radical constructivist approach in British Columbia with a prescribed curriculum, required provincial examinations, and teachers as agents of the state.

## Constructivist Teaching Approaches and Strategies

Airasian and Walsh (1997) proposed that teachers should not use one particular constructivist-based teaching method exclusively. Phillips (1995) viewed the interactive-constructivist approach as a 'middle ground' in the constructivist continuum. Colburn (1998) and Yager (1991) suggested that teachers subscribing to the constructivist model may not have to completely overhaul their teaching methodology but merely reorganize and shift the emphasis of their current teaching (Table 2). Some teachers, in particular the ones that stand out in students' minds as their best teachers, have used constructivist-based teaching strategies intuitively. Teaching approaches such as the learning cycle, four-part guided inquiry, open-ended inquiry, and jig-saw cooperative learning are consistent with constructivist theory. Other teaching strategies that encourage students to construct knowledge include demonstration of discrepant events, student journals, concept mapping, and questioning. These strategies are useful in the science classroom but may apply to other disciplines.

## Modified Learning Cycle (Engage, Explore, Consolidate, Assess)

Interactive-constructivist science teaching can utilize a modified learning cycle called four-part guided inquiry with four phases: engage, explore, consolidate, and assess (Yore & Beugger, 1989). This teaching approach is flexible but provides structure for the elementary teacher and

students and may be used with all types of inquiry (inductive, deductive, semi-deductive, hypothetico-deductive) while providing a scaffold for critical thinking.

Table 2: The *National Science Education Standards* for Teaching (NRC, 1996, p. 52)

| Less Emphasis on: | More Emphasis on: |
|---|---|
| •Treating all students alike and responding to the group as a whole | •Understanding and responding to individual students' interests, strengths, experiences, and needs |
| •Rigidly following curriculum | •Selecting and adapting curriculum |
| •Focusing on student acquisition of information | •Focusing on student understanding and use of scientific knowledge, ideas, and inquiry processes |
| •Presenting scientific knowledge through lecture, text, and demonstration | •Guiding students in active and extended scientific inquiry |
| •Asking for recitation of acquired knowledge | •Providing opportunities for scientific discussion and debate among students |
| •Testing students for factual information at the end of the unit or chapter | •Continuously assessing student understanding |
| •Maintaining responsibility and authority | •Sharing responsibility for learning with students |
| •Supporting competition | •Supporting a classroom community with cooperation, shared responsibility, and respect |
| •Working alone | •Working with other teachers to enhance the science program |

The engage phase of the lesson is intended to motivate and focus students on the subsequent lesson and to access and challenge the students' prior knowledge recognizing the constructivist premise that students come to the science lesson with prior knowledge rather than as an empty container waiting to be filled with knowledge. Accessing prior knowledge assists both the student and the teacher. Students' prior knowledge provides them a foundation on which to build understanding when presented with new experiences. The teacher accesses a

student's prior knowledge to assist in adjusting a lesson to meet the needs of the student (Ausubel, 1968). Should the students' prior knowledge contain misconceptions, the lesson will need to challenge these misconceptions and set the stage for conceptual change. Colburn (1998) suggested that a question or challenge be posed by the teacher to engage student ideas and increase motivation. Student-initiated questions provide a rich source of information to assist the teacher in assessing prior knowledge and promoting student motivation and problem focus (Yager, 1991). Demonstrating discrepant events, completing a K-W-L chart, and using children's literature as springboards into inquiry are other approaches directed at accessing students' prior knowledge, challenging students' ideas, and setting lesson purpose.

The explore phase addresses building knowledge through the interactions of prior knowledge, concrete experiences, and sociocultural discourse. The explore phase encourages students to "collect and process data to develop understanding by thinking, doing, seeing, talking, and reading" (Yore & Beugger, 1989, p. 12). The activities or experiences can include investigations, inquiries, debates, role plays, readings, videos, games, and computer simulations. The teacher's focus is on providing an experience that matches the intended learning outcomes, students' cognitive abilities and prior knowledge, and teacher's abilities and preferences.

The consolidation phase focuses on amalgamation of isolated experiences, evaluations of alternative interpretations, integration of new and old ideas, elaboration of ideas, and application of ideas to relevant real-world problems. This teaching approach recognizes that students construct their understanding from their experiences, but few students develop a conceptual understanding by simply completing an activity without the supportive scaffolding of a teacher (Martens, 1999). Colburn (1998) suggested that, once students have been exposed to new experiences and ideas by doing an activity, then the students need to synthesize that information and use the resulting ideas in a new context to solidify their understanding. Yager (1991) proposed integration and application should include sharing information, constructing new explanations, explaining models, applying new knowledge and skills, and asking new questions. The consolidate phase allows students to share their experiences in a small-group or whole-class setting. The discussion is guided by the teacher through a series of questions or tasks that begin

with the most basic of sharing information, progresses to analyzing that information, making a generalization about the information, and finally applying this generalization to a new situation or to other relevant situations (Yore & Beugger, 1989).

Assessment in a constructivist context should not be simply a final event; rather, assessment is distributed across the learning experience and unit of study to empower learning and inform instruction. During the engage phase, the teacher assesses to find out what the students already know and to inform instruction by adjusting the lesson to the students' prior knowledge. If the students' prior knowledge contains misconceptions, the teacher needs to ensure that the learning activities in the explore and consolidate phases challenge and monitor the misconceptions. Assessment during the explore phase of the lesson provides the teacher with the opportunity to adapt instruction for individuals or small groups by crafting questions and modifying tasks that encourage attention, data collection, analysis, action, problem-solving, and thinking. This also allows the teacher to observe the process skills, cooperative group skills, and habits of mind for individual students. Assessment during the consolidation phase of the lesson allows the teacher to evaluate whether the conceptual goals of the lesson have been achieved. This assessment may be based on student responses to a scaffolded questioning sequence, student responses to embedded evaluative questions, or a task completed by the students during the explore phase. The teacher may ask the students to revise a completed task or apply the knowledge gained from the activity to a different situation. The teacher may use assessment information from these sources for both formative and summative evaluation.

## Questioning Strategies

Questioning strategies can often be the key to a successful constructivist-based lesson and is likely the most difficult pedagogical strategy for preservice teachers to master. Questioning is an effective way for a teacher to find out students' ideas or preconceptions at the beginning of the lesson (Colburn, 1998). Questioning can also help stimulate, redirect, extend, and develop students' thinking. Productive questions can scaffold or encourage students to construct understandings and help teachers to guide students toward a desired understanding (Martens,

1999). When a teacher is attempting to implement interactive-constructivist teaching and students are not moving towards understanding of the concept being explored, the teacher should use questions related to the desired action or result to direct and support students. Martens (1999) suggested six types of questions (attention-focusing, measuring and counting, comparison, action, problem-posing, and reasoning) that will move the student forward in the thinking process during the explore phase (Table 3). The questions are not meant to be sequential, but rather the selection of the type of question is driven by the needs of the student and asked just-in-time to promote knowledge building.

Table 3: Productive Questions (Martens, 1999, p. 26)

| Question Type | Purpose | Examples |
|---|---|---|
| Attention-focusing | Draw student attention to significant details | Have you seen...?<br>What have you noticed about...?<br>What are they doing?<br>What does it feel/smell/look? |
| Measuring and counting | Encourage students to be more precise about their observations | How many...?<br>How often...?<br>How long...?<br>How much...? |
| Comparison | Encourage students to analyze and classify | How are these the same or different?<br>How do they go together? |
| Action | Encourage students to make predictions or observations based on events | What happens if...?<br>What would happen if...?<br>What if...? |
| Problem-posing | Assist students to plan and implement solutions to problems | Can you find a way to...?<br>Can you figure out how to...? |
| Reasoning | Encourage students to think about experiences and help them make sense of these experiences | Why do you think...?<br>What is your reason for...?<br>Can you invent a rule for...? |

These questions are often asked both by teachers and other students during the explore phase and are meant to keep students 'on track' in terms of thinking, inquiry, and behaviour. The timing of

these questions is important since the question asked by the teacher can either stimulate or discourage student thinking. The type of question that the teacher asks is critical in stimulating students to complete the activity. The attention-focusing questions can help those groups getting behind to become interested and involved again, while the groups who finish early are ready for the reasoning type questions that further their thinking and help them consolidate isolated ideas and build meaningful understanding.

Teacher Beliefs and Teaching

A necessary first step toward implementing science education reform is to define the desired image of instruction that can be realized in actual classroom practice. Haney *et al.* (1996) suggested that reforms are destined to fail if implementation efforts do not consider the role of teachers' beliefs, intentions, and attitudes in addition to developing the desired teaching skills. Many teachers are already implementing classroom practices consistent with current science education reform (science literacy for all, understanding the nature of science, and using constructivist-based science teaching). Other teachers agree with the reform ideas and accompanying classroom practice but may not be implementing the appropriate changes in their classrooms. Some classroom observations have shown that the science instruction taking place in the classroom is not inquiry-based science. Simmons *et al.* (1999) conducted a three-year study to explore the beliefs of beginning secondary science teachers and the connection to their actual classroom practice. The teachers in the study were observed in their first year of teaching and again in the second and third years of teaching. In this first year, teachers described their instruction as student-centered; however, the classroom observations indicated that teacher-centered instruction was taking place. These science classroom observations revealed the teacher in the dominant role of dispensing knowledge to the students. This study indicated that as the teachers "gained experience (i.e., their third year), their beliefs and actions became more congruent — albeit more teacher-centered" (Simmons *et al.*, 1999, p. 947).

King *et al.* (2001, p. 106) also found a "great disparity between what the teachers stated was their practice and the reality of the situation". The teachers in this case study included

novice and experienced elementary teachers. The teachers felt that they taught with an inquiry-based approach; however, inquiry teaching was not evident in any of the cases. The teachers relied on the textbook and instruction that were described as expository or traditional in its approach, in spite of the fact that the teachers in this study had been provided with professional development to encourage the use of inquiry-based science instruction. Shymansky *et al.* (2001) explored whether elementary science teachers in a local systemic change project resonate with the fundamental principles of the current science reforms, whether they see themselves as implementing these principles in their science teaching, and whether they actually demonstrate these principles in their classroom science teaching. Correlations revealed non-significant positive and negative associations among beliefs, perceptions, and classroom performance. Regression analyses revealed that significant relationships between science teaching, beliefs, and perceived implementation did not exist for these experienced teachers at the beginning of this local systemic change.

Previous research has shown that preservice teachers have adequate conceptions of some elements of the contemporary view of the nature of science but misconceptions about other elements (Abd-El-Khalick *et al.*, 1998; Lederman, 1992; Lederman & Zeidler, 1987). These beliefs, adequate or not, are not translated into classroom practice (Abd-El-Khalick *et al.*, 1998; Brickhouse, 1990; Lederman, 1992; Lederman & Zeidler, 1987). The research into the relationship between beliefs and classroom practice has revealed several issues that may impede the translation of beliefs into practice.

Overcoming the Barriers to Implementation

Bencze and Hodson (1999) suggested that it is unrealistic to expect teachers to implement constructivist teaching strategies and a contemporary view of the nature of science in their classroom when their own experiences as students were based on a traditional, absolutist view of science and a deductive lecture-verification laboratory approach to science teaching. Although preservice teachers may show an interest in the nature of science, they often have misconceptions about the ontology and epistemology of science, are not aware of the underlying

assumptions' importance to science education, and do not have strategies that will assist them in incorporating these ideas into instruction (Clough, 1998).

Regardless of the beliefs about the nature of science that teachers hold, they often perceive that the nature of science is a less important outcome than outcomes associated with science process and content (Abd-El-Khalick *et al.*, 1998). Further constraints such as preoccupation with classroom management, lack of resources, pressure to cover content, and lack of time for planning are barriers to the implementation of the nature of science in the classroom (Abd-El-Khalick *et al.*, 1998; Bell & Lederman, 2000). Additional barriers have been identified by preservice teachers in their attempts to translate their beliefs about the nature of science into classroom practice, concerns for student abilities, institutional constraints such as lack of mentoring, and lack of teaching experience (Bell & Lederman, 2000).

Many of the barriers that interfere with the translation of nature of science into practice also impede the implementation of constructivist teaching. One of the barriers to implementation of constructivist-based teaching strategies may be the lack of experience that teachers and the students have with this type of teaching and learning. Constructivist approaches require teachers and students to assume unfamiliar roles. The teachers need to assume the role of guiding and facilitating, and the students need to become more active and self-regulated in their own learning. Assessment has to be viewed as an opportunity for both students and teachers to empower learning and inform instruction. Furthermore, the pressures of having to spend extra time in planning and teaching, classroom management difficulties, coupled with the lack of curriculum materials present additional barriers to implementing constructivist strategies for teachers (Beck *et al.*, 2000).

The implementation of constructivist-based teaching strategies is not an automatic and short-term goal. Hand (1996) suggested that teachers progress through stages—beginning with no knowledge of constructivist-based teaching, moving to a mechanical, almost structured application of constructivism, to finally completely focusing on student-directed learning. Louden and Wallace (1994) suggested that the shift of teachers and students to constructivist-based teaching and learning may involve a conceptual change approach and the implementation of

strategies through the gradual accommodation and assimilation of these new strategies by both students and teachers.

Inquiry science activities that are consistent with an interactive-constructivist and the contemporary view of science are often difficult for teachers to implement in the classroom. Inquiry-based activities encourage students to use their prior knowledge to formulate a plan for investigation. The students investigate the problem in a variety of ways unique to each investigator—many of which may not be fully productive, controlled experiments. The teacher's role is to facilitate this diversity, to ensure classroom safety, and to guide the process but not determine the method nor overly confine the learning experience. The expectation that preservice teachers, whose priority is on the unfamiliar tasks of classroom management, relating to students, and the organizational structure of teaching, can implement complex inquiry strategies in an elementary science classroom may not be feasible considering their professional and pedagogical development (Bell & Lederman, 2000; Lederman, 1999). Crawford (1999) concluded that there were six factors that assisted preservice teachers in their efforts to implement an inquiry-based classroom. The factors included prior experience with this type of exploration, experience with an inquiry-based classroom, a clear vision of the unit goals, developing a trust relationship with the classroom teacher, collaboration with experts outside of the classroom, and reflective practice.

Nature of Science and Constructivist Approaches in Preservice Methods Courses

Mellado (1998) suggested that acknowledging preservice teachers' prior conceptions about teaching and learning is not enough to change teaching behaviour. Preservice methods courses must also provide opportunities for the teacher to "redefine their teaching strategies, contrast them with their previous beliefs, and again put them into practice" (Mellado, 1998, p. 210). Reflective practice in preservice teachers is important not only in developing their beliefs but also in developing their professional practices (Akerson & Abd-El-Khalick, 2000; Hewson *et al.* 1999; Mellado, 1998). Elementary science methods courses must provide more than the underlying theories of learning. The instruction of preservice teachers should provide the

strategies and procedures to use in the classroom that exemplify the theory and should be taught in a manner that is consistent with the theories of learning and teaching being promoted.

There has been much research into how to develop preservice science teachers' understanding of the nature of science including how to change their prior conceptions (Lederman, 1992). Instruction about the nature of science could be provided in a separate course in the history and philosophy of science, in undergraduate science courses, or within a science methods course. However, taking a course on the history of science outside the context of classroom applications may provide information on the subject, but does not provide explicit connections to science teaching and does not approach the nature of science from the same perspective as science educators (Clough, 1998; McComas *et al.*, 1998). Providing nature of science instruction to preservice teachers in an undergraduate science course may not be an appropriate option either. Most science experiences at the first and second year undergraduate level focus on acquiring content and completing cookbook laboratory experiments. These types of courses do not provide preservice teachers with an understanding of "the thinking and behavior of scientists" (Matson & Parsons, 1998, p. 223). Although there is general agreement that the nature of science should be taught within the context of a science methods course, there is some debate about the value of implicit versus explicit teaching methods (Lederman, 1999; Palmquist & Finley, 1997).

The explicit method of teaching combines inquiry activities with embedded explicit instruction on the nature of science. Implicit instruction presents science process instruction without direct instruction on the nature of science. This type of instruction assumes that the various aspects of the nature of science will be realized as a result of completing process activities. Overall however, there appears to be some agreement among researchers that teaching the nature of science is best achieved through explicit instruction within the context of a science methods course (Abd-El-Khalick *et al.*, 1998; Akerson *et al.*, 2000; Clough, 1998). Akerson and Abd-El-Khalick (2000) used a conceptual change approach and direct explicit instruction with reflective components to change preservice teachers' conceptions of the nature of science in an elementary science methods course. Conceptual change theory proposes that in order for ideas to

change, the student must be dissatisfied with her or his existing ideas and the new ideas must be plausible, acceptable, and powerful. The students were made aware of their conceptions and were given readings and activities that would assist them in confronting their misconceptions. The activities were not content specific and were "followed by a whole class discussion that aimed to explicitly highlight the target aspect of nature of science" (Akerson & Abd-El-Khalick, 2000, p. 6). The instructor asked the students to describe how the science content and pedagogy related to the nature of science through verbal discussions and papers that were written in reaction to specific readings and videotapes. The effect of this conceptual change-reflective activity approach demonstrated that participants made significant gains in their understandings of the nature of science. However, this was a one semester course and participants indicated that their understandings of nature of science were still tentative and required further development. The study did not address the issue of whether the preservice teachers' ideas about the nature of science were successfully translated into classroom practice.

The goal of science literacy, including an understanding of the nature of science, should not be limited to students in kindergarten to grade 12. Elementary science methods courses should also consider science literacy as a goal for preservice teachers. Teachers who are able to make informed decisions about science knowledge based on the ontological assumptions about reality and the epistemological criteria of science (claims, evidence, warrants) will be better able to make instructional decisions in their classrooms. There appears to be little research that examines the relationship between the use of the explicit instruction in a science methods course and preservice teachers' beliefs about the nature of science and the effect this approach has on the degree to which preservice teachers translate constructivist and the nature of science ideas into their classroom practices.

## Research Design

This case study examines preservice elementary teachers' beliefs about the nature of science prior to and after participating in an undergraduate science methods course and the impact

that their beliefs about the nature of science have on their planning and teaching. This case study explored the following research questions within a well-defined program and cohort of students:

- What are these elementary preservice teachers' beliefs about the nature of science prior to completing an elementary science methods course?
- What changes occur to the beliefs of preservice teachers after explicit instruction on the contemporary view of the nature of science in an elementary science methods course?
- How do the preservice teachers' beliefs about the nature of science affect their classroom practice?

This study used a hybrid pretest and posttest case study design to measure two cohorts of preservice teachers' beliefs about the nature of science before and after participation in an elementary science methods course and intervening teaching practicum. The design employed embedded qualitative methods involving multiple classroom observations of a small purposeful sample of preservice teachers from the two cohorts. Further documentation of these preservice teachers' classroom practice included unit overviews, lesson plans, and assignments. These instructional artifacts provide a basis for triangulation of the assertions.

## Data and Participants

The *Nature of Scientific Knowledge Scale* [NSKS] (Rubba & Andersen, 1978) was used to assess the preservice teachers' beliefs about the nature of science. The NSKS purports to be an objective measure of secondary students' beliefs of the nature of science described earlier. A detailed description of the content selection, validity, and reliability can be found in the original study (Rubba & Andersen, 1978). The NSKS was selected on its match to the nature of science described earlier and to provide an established marker to other studies that aid in the generalization of this case study results (Firestone, 1993; Yore, 2002).

The classroom observations were done by the first author in an observer-participant role with no evaluation responsibilities for the practicum (Gall *et al.*, 1996). This researcher, an experienced supervisor of elementary science instruction, was primarily an observer who entered

the classroom setting to gather data and interacted with individuals in the setting indirectly. The classroom observations occurred during the initial 6-week November-December practicum and focused on lesson structure and sequence, questions and responses of teachers and students, and the type of assignments given by the teacher.

The 54 students in this study were enrolled in two sections of the course; all of them voluntarily participated in the survey portion of the study. The students were in the 4th and 5th year of a five year B.Ed. degree and had a variety of science backgrounds. Thirty-seven of the preservice teachers had completed the basic 3-unit laboratory science course requirement to enter the Faculty of Education, 15 had completed additional science courses such as second year or additional first year biology, physics or earth science courses, and two had completed BSc degrees in biology and biochemistry. As is typical in many elementary teaching programs, there were more female (N = 45) than male (N = 9) students in the sample.

Initially 27 volunteers were reviewed for classroom observations using the first assignment for their science methods course - a description of their practicum class, classroom, and assigned science topic. One of the original 27 volunteers discovered at this stage that her practicum did not include a science teaching assignment and as a result was eliminated from the sample. Other volunteers were removed from the pool for reasons such as placement in a French immersion classroom (the observer is unilingual), an assignment that involved team teaching, a science teaching assignment that was not a topic from the prescribed curriculum, the traveling distance to the practicum school for the observer was too far, or the practicum was at an alternative school. The review process resulted in a pool of 13 preservice teachers as possible subjects for participation in the classroom observations. The teaching assignments of the remaining 13 volunteers were in classrooms from grades 1 to 7 and included topics from the physical science, life science, and earth and space science. The second assignment for the science methods course, a unit overview, was used to select a purposeful sample of six preservice teachers. The criteria that were used in this selection included: presence of science content, opportunities to teach constructivist-based lessons, a balance of primary (K-3) and intermediate (4-7) grades, a balance of the science domains (physical science, life science, earth/space science),

and a representation from both cohorts of the methods course. There were three volunteers from each cohort in the final selection (Table 4). All six of the final volunteers were female. This situation was not a purposeful decision on the part of the researcher but was a consequence of a skewed gender distribution in the original pool of volunteers. The names used for these students are pseudonyms.

Table 4: Volunteers for Classroom Observations

| Name | Susan | Mary | Kara | Linda | Julie | Kelly |
|---|---|---|---|---|---|---|
| Grade | Grade 7 | Grade 4/5 | Grade 4/5 | Grade 3 | Grade 1 | Grade 1 |
| Topic | Ecosystems | Light & Colour | Skeletal System | Earth's Composition | Weather & Seasons | States of Matter |
| School | School B | School E | School F | School G | School J | School F |

The Science Education Experience

The science methods course was co-taught by the authors with 6 years and 30 years experience respectively teaching this course. The 54 participants were taught the same material in two separate cohorts. The science methods course was one of five courses that the preservice teachers were required to complete in the professional year (a year that includes two practical experiences scheduled in six-week blocks - November/December and April/May). Nature of science was a central theme of the course; students were expected to provide a strong rationale for the instructional decisions included in their assignments, examinations, and teaching.

The content of the course in the first eight weeks focused on providing students with an introduction to the nature of science, basic science processes, four-part guided inquiry teaching method, and basic assessment methods. Prior to any formal instruction about the nature of science, the students were asked to provide a list of words and phrases that they associated with the discipline of science. These beliefs were examined and discussed in the context of two articles on the nature of science ("Ten Myths of Science: Re-examining what we think we know about the nature of science, McComas, 1996; A Passion within Reason: The Human Side of Process, Cross, 1990). Two activities (Baggie Science; Science in a Bag) showed the tentative nature of

science and inductive reasoning. Any discrepancies between the students' ideas and the ideas presented in the two articles were discussed, and attempts were made to resolve any misconceptions that the students may have held. Throughout the rest of the methods course, the students were explicitly taught aspects of the nature of science; and these were reinforced using in-class activities that could be used with elementary students. The assignments for the first 8-week term were designed to prepare the preservice teachers for their initial 6-week practicum and encouraged them to incorporate the four-part guided inquiry lesson format and hands-on explorations into their required science teaching. These assignments included a classroom description, unit overview, one four-part guided inquiry lesson plan, and a mid-term examination.

The second term was 10 weeks followed by another 6-week practicum. The focus of this part of the course was on the integrated science processes and on expanding and refining the repertoire of teaching strategies consistent with an interactive-constructivist teaching model. There was explicit instruction on the nature of science and how the teaching strategies presented portrayed the consensus view of the nature of science. The assignments for the second term included reflections on their science teaching experience in the first practicum, a reaction paper for an article from a science teaching journal, a professional development portfolio, and a final examination. The portfolio assignment was intended to provide an opportunity for students to synthesize the course goals and to provide an opportunity "to document and describe their teaching; articulate their professional knowledge, and reflect on what, how and why they teach" (Moseley, 2000, p. 39). The first part of the portfolio assignment required the preservice teachers to write a one-page to two-page summary of their beliefs about the nature of science, their science teaching philosophy, and their thoughts on how children can best learn science (learning theory). They were encouraged to consider some key words for this section (nature of science, scientific literacy, constructivism, hands-on/minds-on). The summary was also to include specific examples of teaching strategies that they would use in their science lessons and that align with their stated beliefs.

## Quantitative Results

The pretest and posttest minimum scores, maximum scores, means, and standard deviations were calculated for the total NSKS and the six subscales to provide an overview of the results of 50 students who completed both the pretest and the posttest. Four students did not complete both the pretest and posttest because of late entry into the course or illness at the end of the term. These four students were female; two of these students had basic 3-unit laboratory science course requirement and the other two students had completed additional science courses. The deletions of these four students did not appear to change the characteristics of the two cohorts.

### Preservice Teachers' Beliefs about the Nature of Science

The preservice teachers generally expressed more distinctive beliefs about the nature of science on the posttest than they did on the pretest (Table 5). Inspection of the survey responses revealed that there were more extreme responses (strongly agree, strongly disagree) on the posttest than on the pretest. The mean performances on the pretest and posttest were judged to be good (>168 on the NSKS and >28 on the subscales). The mean pretest performance on the testable subscale was judged to be very good (>32) leaving less room for improvement. The mean total score and the mean score for each subscale increased from the pretest to the posttest. The largest gain in mean score for a subscale was made on the creative subscale. The range (actual maximum - minimum) of the scores increased on three subscales (amoral, parsimonious, unified), decreased on two subscales (creative, testable), and stayed the same on one subscale (developmental).

Table 5: Descriptive Statistics of Pretest and Posttest Subscale Scores (N=50)

| NSKS Scale | Administration | Min | Max | Mean | SD |
|---|---|---|---|---|---|
| Total | Pretest | 150 | 201 | 172.10 | 13.89 |
| | Posttest | 154 | 226 | 181.62 | 14.81 |
| Amoral | Pretest | 19 | 38 | 27.10 | 4.51 |
| | Posttest | 14 | 39 | 27.82 | 5.07 |
| Creative | Pretest | 11 | 35 | 26.94 | 5.20 |
| | Posttest | 22 | 39 | 31.34 | 4.29 |
| Developmental | Pretest | 25 | 37 | 30.66 | 2.72 |
| | Posttest | 27 | 39 | 32.86 | 3.19 |
| Parsimonious | Pretest | 16 | 32 | 23.68 | 3.25 |
| | Posttest | 16 | 37 | 24.48 | 4.05 |
| Testable | Pretest | 25 | 40 | 32.60 | 3.60 |
| | Posttest | 26 | 39 | 32.66 | 3.67 |
| Unified | Pretest | 24 | 39 | 31.12 | 3.40 |
| | Posttest | 19 | 39 | 32.46 | 3.90 |

A Pearson correlation matrix was completed between the students' NSKS total scores (pretest, posttest) and their marks received on assignments within their science methods course, including a unit overview, lesson plan, portfolio assignment, and the midterm and final examinations (Table 6). Correlation coefficients between the pretest NSKS scores and the marks for the assignments or examinations in the methods course ranged from -0.07 to 0.14. The correlation coefficients between the posttest NSKS scores and the marks for the assignments and examinations in the methods course ranged from -0.19 to 0.32. The posttest NSKS and the mid-term examination score was the only correlation coefficient greater than the critical correlation coefficient of 0.28 ($N=50$, $p \leq 0.05$). However, it was surprising to find the negative correlations between students' pretest NSKS scores and their planning to teach science since most of the unit plans and lesson plans presented science as inquiry, a balance of science processes, knowledge, and attitudes, and followed the modified learning cycle structure.

Table 6: Correlation Matrix for NSKS Total Score and Course Assignments and Examinations (N=50)

| NSKS | Unit Overview | Lesson Plan | Midterm Exam | Portfolio | Final Exam |
|---|---|---|---|---|---|
| Pretest | 0.04 | -0.07 | 0.07 | 0.14 | 0.02 |
| Posttest | -0.19 | -0.02 | 0.32* | 0.10 | 0.16 |

*significant ($p \leq 0.05$)

Changes in Preservice Teachers' Beliefs about the Nature of Science

A paired sample t-test was used to determine if gains between pretest and posttest scores on each subscale and the total NSKS scores were greater than what would be expected by chance (Table 7). There were significant ($p \leq 0.05$) differences between the pretest and posttest scores for the overall score and three of the six subscales (creative, developmental, and unified). There were non-significant ($p \geq 0.05$) differences between the pretest and posttest scores for the other three of the six subscales (amoral, parsimonious, and testable).

Table 7: T-test Analysis of Pretest and Posttest Differences (N=50)

| NSKS Subscales | Mean Difference | t | Df | p-value |
|---|---|---|---|---|
| Total Score | 9.52 | 5.53 | 49 | 0.00 |
| Amoral | 0.72 | 0.97 | 49 | 0.34 |
| Creative | 4.40 | 5.74 | 49 | 0.00 |
| Developmental | 2.20 | 5.56 | 49 | 0.00 |
| Parsimonious | 0.80 | 1.54 | 49 | 0.13 |
| Testable | 0.60 | 0.12 | 49 | 0.91 |
| Unified | 1.34 | 2.55 | 49 | 0.01 |

Case Study Results and Assertions

Six preservice teachers were selected as a non-random cohort for the embedded qualitative component of this study that attempted to explore whether their beliefs about the nature of science influenced their classroom practice. A description of these preservice teachers was provided to facilitate limited generalization deemed appropriate. The classroom observation cohort's mean total score and mean subscale scores were higher than the class means for the total NSKS and the six subscales (Table 8). Pretest scores were used in this part of the study since they most closely approximated the timing of the classroom observations.

Table 8: Pretest Means and Standard Deviations for the Class and the Observation Cohort

| NSKS Subscale | Class (N=50) | | Case Study Cohort (N=6) | |
|---|---|---|---|---|
| | Mean | SD | Mean | SD |
| Total Score | 172.10 | 13.89 | 181.33 | 9.20 |
| Amoral | 27.10 | 4.51 | 30.33 | 4.76 |
| Creative | 26.94 | 5.20 | 29.00 | 4.43 |
| Developmental | 30.66 | 2.72 | 31.33 | 2.58 |
| Parsimonious | 23.68 | 3.25 | 24.33 | 2.66 |
| Testable | 32.60 | 3.60 | 34.50 | 3.39 |
| Unified | 31.12 | 3.40 | 31.83 | 3.25 |

Members of the case study cohort had scores that varied in their relationship to the class and cohort means (Table 9). Preservice teachers in the case study are identified according to their pretest survey scores and comparisons to the class and cohort scores where the classroom observations are interpreted. The analysis of the observations focused on the unit plans, implementation of constructivist teaching (engage, explore, consolidate, assess), types of questions posed by the teacher, responses by students, types of assignments, and general comments about the practicum situation.

Table 9: Individual Case Study Subject Pretest Scores

| | Susan | Julie | Mary | Kelly | Linda | Kara |
|---|---|---|---|---|---|---|
| Total | 191 | 190 | 184 | 182 | 173 | 168 |
| Amoral | 29 | 38 | 34 | 29 | 26 | 26 |
| Creative | 35 | 23 | 29 | 32 | 25 | 30 |
| Developmental | 35 | 28 | 32 | 31 | 33 | 29 |
| Parsimonious | 25 | 25 | 28 | 20 | 25 | 23 |
| Testable | 33 | 40 | 33 | 36 | 35 | 30 |
| Unified | 34 | 36 | 28 | 34 | 29 | 30 |

A summary of the relationship between the six preservice teachers' beliefs about the nature of science (NSKS scores) and their science teaching are reported as assertions. The assertions constructed from these data are expressed in **bold face** type, supporting quotes from the classroom observations are expressed in *italics*, while the researchers' elaborations are expressed in normal type.

**It is unrealistic to expect preservice teachers to adequately implement the complex elements of inquiry teaching during their first practicum experience.**

The first eight weeks of science methods instruction focused on inquiry, and their assignment marks indicated that the six preservice teachers had a good understanding of the elements of inquiry teaching (engage, explore, consolidate, assess). However, none of the six preservice teachers observed demonstrated all elements of the modified learning cycle at an adequate level in the classroom teaching observed. All six preservice teachers observed achieved good (80%) to excellent (95%) on their instructional planning activities for science. The marks for the unit overviews ranged from 12.5 to 13.5 out of a possible 15 marks. The marks for the lesson plan ranged from 8.0 to 9.5 out of a possible 10 marks. These instructional artifacts contained evidence of science as inquiry, the linkage between evidence and claims, and science processes. Classroom observations that focused on evidence and quality of the engage, explore, consolidate,

and assess phases of the modified learning cycle indicated that only two of the six preservice teachers demonstrated satisfactory performance on all four phases over the two lessons observed.

**A high NSKS score does not imply effective implementation of the phases of a modified interactive-constructivist learning cycle by the preservice teachers.**

The desired image of the interactive-constructivist learning cycle suggests that teaching involves engaging students, providing opportunities for exploring and experiencing science events, promoting consolidation, elaboration and application of new knowledge, and assessing student inquiry, habits of mind and science understandings (Beeth & Hewson, 1999; Colburn, 1998; Henriques, 1997; Schulte, 1996; Shymansky *et al.*, 1998; Yore & Beugger, 1989). The following sections describe what was expected and what was observed for the four phases of the modified learning cycle.

Engage

During the engage phase teachers should motivate, establish problem focus, and access, challenge, and assess prior knowledge. The teacher's questioning should encourage divergent responses and allow for student-generated questions to set the central purpose for the exploration. The preservice teachers with high NSKS scores used traditional introductory strategies, while preservice teachers with lower NSKS scores used more inquiry-oriented engagement strategies. Susan (high NSKS score) and Julie (high NSKS score) began their lessons with a review of a prior lesson reinforcing facts and lower-level ideas and provided teacher-directed instruction to establish purpose, procedures, and behaviour expectations for the coming lesson. During one lesson, Susan stated:

> *Let's review yesterday. Tell me about the water cycle. What makes it a cycle? Today we are going to cover one more cycle, the nitrogen cycle. Where does the nitrogen cycle exist? (Observation Notes, December 7, 2000)*

Julie began her lesson using the following statement:

> *This morning we watched a video on weather and wind was part of weather. Now we are going to make a pinwheel and use it with different types of wind. (Observation Notes, December 11, 2000)*

Kelly (mid-range NSKS score) also reviewed the previous lesson in the engage phase. After the review, she performed a demonstration related to the current lesson concept that involved putting a rock in a glass of water. She asked the students the following:

> *What did you notice? Why do you think this happens? Does anyone think that air takes up space? (Observation Notes, December 14, 2000)*

Linda (low NSKS score) accessed prior knowledge during the engage phase after a review of the previous lesson concepts. She began the lesson with the following:

> *What do you think soil is made of? The word 'soil' is printed on the board. Connections were made to the students' suggestions. Student suggestions included: dead animals, worms, manure, garbage, dirt, leaves, roots, minerals, compost, and vegetables. (Observation Notes, December 13, 2000)*

Explore

The ideal explore phase is characterized by open-ended investigations that involve collecting evidence used to construct a knowledge claim. The teacher should act as facilitator and use a variety of questions to stimulate action and extend thinking. The selection of question is driven by the needs of the student and asked just-in-time to promote inquiry, data collection, and knowledge building (Martens, 1999). The preservice teachers with high NSKS scores appeared to use more structured explorations than the preservice teachers with lower NSKS scores. Susan (high NSKS score) asked her students to make a drawing of the nitrogen cycle. She stated:

> *Draw the nitrogen cycle. Fold your paper in half; use the top half of the paper for your drawing. Let's review the parts of the nitrogen cycle that you need in your drawing. (Observation Notes, December 7, 2000)*

Mary (mid-range NSKS score) encouraged her students to collect evidence to support a claim about the central research question in the inquiry investigating light. She used the following instructions on their worksheet:

> *What could you see when the tube was bent at right angles? What could you see when the tube was straight? What does this tell you about how light travels? (Observation Notes, December 12, 2000)*

Kelly (mid-range NSKS score) used a variety of questions during a demonstration about air occupying space to stimulate and extend student thinking. She used the following questions:

> *What will happen to the napkin if I put the glass upside down in the bowl of water? (Student responses included: Stay dry, get wet, disintegrate, absorb all of the water in the bowl) What happened to the paper towel? Why do you think the paper towel stayed dry? How could I get the paper towel in the bottom of the glass wet if I put it upside down in the water? (Student response: Tip the glass) Did anyone notice what happened when I did that? Where did the bubbles come from? (Observation Notes, December 14, 2000)*

Kara (low NSKS score) provided materials for designing and testing the strength of two different bone types and then directed the students to collect evidence and make a claim based on that evidence. She stated:

> *Build the different bones, stand the bones up on a flat surface. Put one book at a time on top of the bone. Should you be able to hold the bone? Why not? (Student response: Holding the bone will add strength). Decide which bone type you think is the strongest and why you think that. (Observation Notes, November 16, 2000)*

Consolidate

The ideal consolidation phase should scaffold student's construction, integration, elaboration, and application of science understanding. Consolidation may occur in individual students, small groups, or whole class settings and should involve both public and private dimensions. This phase is characterized by pooling information from the explore phase (evidence), which leads to a generalization (claim). The pooled information may contain

conflicting ideas and may be examined for procedural differences, sampling problems, or observing errors. Alternative interpretations of the evidence are evaluated and the 'best fit' solution with the available evidence is made as a claim. The claim is then integrated into the students' conceptual network and connected to a real-world application. A scaffolded sequence of questions (share, organize, analyze, generalize, verify, apply) is used to support knowledge construction, integration, elaboration, and application. All of the six preservice teachers regardless of their beliefs about the nature of science (NSKS scores) had their students pool or share their information but did not complete the sequence of scaffolded questions to ensure construction, integration, and application. Susan (high NSKS score) asked the following low-level questions based on recollections from the video watched in the explore phase:

> *What did you see on the video? What is a population? What are some of the different populations that you saw on the video? How do various species cope with crowding? (Observation Notes, December 11, 2000)*

Mary (mid-range NSKS score) used the following questions to encourage students to share information from their experiences:

> *What did you see? Students' responses: I could see part of the man. I could see none of the man. Why couldn't you see the man? What can you say about light? (Observation Notes, December 12, 2000)*

Kara (low NSKS score) began a sequence of questions for the consolidation phase that had potential but did not complete the sequence:

> *What were your results - how many books did each type of bone hold? Why are these numbers different? Was everyone's book exactly the same? Does the length of the bone make any difference? Is there any pattern to the number of books each bone held? (Observation Notes, November 16, 2000)*

Linda (low NSKS score) completed a series of recall questions intended to share ideas but not to promote construction of higher-level understanding during the consolidation phase that was typical of the preservice teachers:

*Who had a sample that could be scratched by pencil lead? Student X found one sample and that means it is really soft. Who has something that could be scratched by a nail? (Observation Notes, November 24, 2000)*

Assess

Assessment should ideally encourage students to demonstrate active inquiry and construct knowledge rather than recall or represent information. It should be authentic and focus on the process as well as the product and utilize a variety of information sources and assessment techniques. None of the six preservice teachers regardless of the NSKS scores implemented authentic formative assessment strategies and only demonstrated traditional assessment techniques in the lessons observed. They marked their students' worksheets and recorded the mark for the purpose of providing a grade. Susan (high NSKS score) stated at the end of a lesson:

*Please hand in your drawings of the nitrogen cycle. I will be marking them and handing them back. (Observation Notes, December 7, 2000)*

Kara (low NSKS score) stated:

*You did well on the sheet from yesterday. Most of you were able to give the scientific name for each bone. Many of you got As and Bs on that assignment. (Observation Notes, November 16, 2000)*

**The NSKS scores (high, mid-range, low) do not predict preservice teachers' use of questions that promote an evaluativist view of the nature of science.**

Questions such as problem-posing and reasoning encourage students to think about the evidence that supports their claims and the creativity involved in scientific inquiries. None of the six preservice teachers consistently used problem-posing questions to extend and redirect inquiry (Can you find a way to…? Can you figure out how to…?) or reasoning questions to promote critical thinking (requiring a judgment and supportive rationale) and make the claims-evidence evaluations explicit (Why do you think…? What is your reason for…? Can you invent a rule for…?) in their teaching. They primarily used attention-focusing questions (Have you see…?

What have you noticed about…? What are they doing? What does it feel/smell/look?) and measuring and counting questions (How many…? How often…? How long…? How much…?) to control and manage the specified tasks assigned or behaviours expected. Susan (high NSKS score) used the following questions in her lesson:

> *What are the different spheres? What is the lithosphere? What is the biosphere? What were the cycles? What is common about all of the cycles? (Observation Notes, December 11, 2000)*

Kelly (mid-range NSKS score) posed the following questions during a lesson:

> *What are some examples of solids? What are some examples of liquids? What are some examples of gases? What do you notice about what is inside this bag? (Observation Notes, November 23, 2000)*

Linda (low NSKS score) asked the following questions:

> *Where does soil come from? What is in soil? What animals did you find? What is in the rock and mineral pile? Are all the rocks the same size? (Observation Notes, December 13, 2000)*

## Discussion

The 50 preservice teachers held reasonably positive perceptions of the nature of science and of scientific knowledge at the beginning of the study. These perceptions improved over the duration of the science methods course and initial teaching practicum. The patterns and range of responses indicated that these preservice teachers were becoming more distinctive in their beliefs about the nature of science, while collectively improving on the NSKS total score and subscales. Their professional development during the 8 months of this study appeared to significantly influence most of their beliefs about the nature of science (total NSKS and the Creative, Developmental and Unified subscales). There was confirming evidence of these beliefs in the first term assignments. Unit overviews and lesson plans indicated that the preservice teachers had a good to excellent understanding of science literacy as a balance of abilities, processes, attitudes, and knowledge and of the inquiry teaching strategies presented. However, the unit plan

and lesson plan marks were not significantly correlated with the NSKS pretest scores, and in the case of the lesson plan marks they were negatively correlated.

This study provided qualified support for the assertion made by previous researchers that explicit rather than implicit instruction is effective in changing the nature of science beliefs (Abd-El-Khalick *et al.*, 1998; Akerson *et al.*, 2000; Clough, 1998). The gains made in the creative, developmental, and unified subscales appear to be, in part, due to the explicit instruction provided in the science methods course on these subscales. The concepts of each of these three subscales had been explicitly addressed through a variety of instructional components (activities, discussions, readings, assignments) associated with creativity in science, development of scientific knowledge over time, and the integrated nature of the scientific knowledge network.

The greatest mean difference between the pretest and posttest on the NSKS was on the creative subscale. Creative subscale questions on the NSKS focused on the belief that science knowledge is a product of human creativity and intelligence (Rubba & Andersen, 1978). There was direct discussion, activities, readings, and an assignment that specifically addressed this aspect of the nature of science, as captured in the subscale. The preservice teachers completed an activity that addressed the concept of the creativity involved in designing an experiment, a 'fair test'.

The developmental subscale on the NSKS exhibited the second greatest overall improvement after the students completed the science methods course. The developmental subscale questions were related to the concept that scientific knowledge was tentative and "is never proven in an absolute and final sense" but is evaluated as further evidence becomes available (Rubba & Andersen, 1978, p. 456). The ideas underlying the developmental subscale were discussed directly at numerous times throughout the methods course. The preservice teachers also addressed this concept in the "Science in a Bag" activity. The debriefing of this activity included a discussion of how each new piece of evidence either refuted or supported the guess that the students had made. The connection to the procedures of science was made during the debriefing of this activity.

The unified subscale had the next greatest mean difference on the NSKS. The unified subscale questions were designed to assess the idea that science knowledge is the result of an effort to understand nature and this knowledge "produced by the various specialized sciences contribute to a network of laws, theories and concepts" (Rubba & Andersen, 1978, p. 456). The concepts associated with the unified subscale were addressed in the methods class during a specific discussion of the nature of science at the beginning of the first term. These beliefs were examined and discussed in the context of two articles on the nature of science.

The absence of pretest versus posttest changes in student beliefs on the amoral and parsimonious subscales might be due to the implicit teaching employed in the course regarding these aspects of the nature of science. The amoral subscale question focused on the idea that science knowledge cannot be judged as good or bad, only the application of the knowledge may be judged. The parsimonious subscale questions were designed to examine the belief that science knowledge attempts to "develop a minimum number of concepts to explain the greatest possible number of observations" (Rubba & Andersen, 1978, p. 456). In contrast to the creative, developmental, and unified subscales, the amoral and parsimonious concepts were not explicitly addressed during the instruction in the science methods course. It is possible, however, that the preservice teachers were able to implicitly discern some aspects of each of these subscales through discussions and activities associated with instruction about the process skills, teaching strategies, and science literacy.

This subscale focussed on science as involving a fair test of speculations and hypotheses. The lack of significant change in the testable subscale was not surprising. The high pretest scores for the testable subscale appear to have created a ceiling effect for the posttest results; in other words, there was little room for improvement between pretest and posttest results.

Regardless of preservice teachers' beliefs about the nature of science, the expectation that preservice teachers are able to successfully implement their beliefs about the nature of science and the elements of inquiry science teaching (engage, explore, consolidate, assess) in an initial practicum experience is unrealistic. The choices between promoting a modern view of science or a traditional view of science and using a constructivist, inquiry teaching approach or a traditional,

teacher-directed approach are influenced by their experiences as students and the approach used by their classroom sponsor teachers. The model of science teaching that preservice teachers have experienced as students, the model of science teaching that they see in their host classroom, and the perceived expectations placed on them by sponsor teachers or university supervisors are in most cases contrary to the interactive-constructivist science teaching presented in the science methods course. Crawford (1999) observed the same barriers to preservice teachers' implementation of inquiry teaching strategies as seen in this study.

Preservice teachers have often experienced science in the traditional stand-and-deliver approach (lecture followed by a verification laboratory) as a student in science courses at the elementary, secondary, and postsecondary levels. The preference of this traditional teacher-directed approach is frequently reinforced by their sponsor teacher during the preservice teachers' practicum experience. The preservice teacher is then faced with the dilemma of choosing between an approach to teaching science that they have experienced and have seen implemented by their sponsor teacher and the inquiry teaching presented by their idealistic science methods professor. Faced with the pressures of wanting to impress the sponsor teacher and facing judgment from the practicum supervisor, and further complicated by a lack of experience and concern about survival and desire to succeed, the preservice teacher is likely to adopt the teacher-directed approach over the inquiry approach.

Finally, many preservice teachers are in the early developmental level of concern about self and subject matter and have not evolved to levels of concern about students and learning. The interactive-constructivist approach requires comfort with self, content knowledge, classroom management, and basic teaching strategies, which then allows preservice teachers to shift their focus to pedagogical content knowledge and to their students' prior knowledge and their struggles to construct and apply science understandings.

## Concluding Remarks

This study suggests that the role of the sponsor teacher and larger educational community may have an influence on whether new teachers are likely to implement contemporary beliefs about the nature of science and inquiry-based teaching strategies early on in their careers. The results suggest that preservice teachers' beliefs about science and knowledge about interactive-constructivist science teaching can be improved during the university-based component of a teacher education program. But the impact of the field-based component of a teacher education program may have over-riding contrary influence. As perceptions about appropriate educational practice change, there is also an expectation of inter-generational changes among teachers. Positive change, however, may be stymied if the practices encouraged by universities in preservice educational offerings are contradicted by the earliest classroom experiences and by mentorship within the teaching community (Yore, 2001). This points to a need to reach practicing teachers to a much greater degree, so that sponsor teachers and colleagues are capable of supporting, not undermining the implementation of inquiry-based, interactive-constructivist methods toward the goals of science literacy.

Teacher education programs need to allow preservice teachers to analyze their own epistemologies and assert what type of teaching strategies best promote and facilitate these ways of knowing. These reflections should consider the differences in the epistemology of different disciplines and realize that science teaching needs to promote the tentative nature of science and science as inquiry. They need to engage in the speculative language of science and the hedging that is part of any research report, and to delay or reserve judgment until alternative interpretations are considered and evaluated against the available evidence from nature. Furthermore, faculty and supervisors involved in the clinical experiences of teacher education programs must accept that early classroom experiences place the highest priority on self and survival, followed by the student teachers' agenda and only much later after these first two levels of concern are addressed, do the needs and perspectives of the students become a priority. In this real world of learning to teach science, the hyper-fine details of the nature of science and inquiry teaching become less important when their knees are knocking and they are anticipating the next revolt.

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